

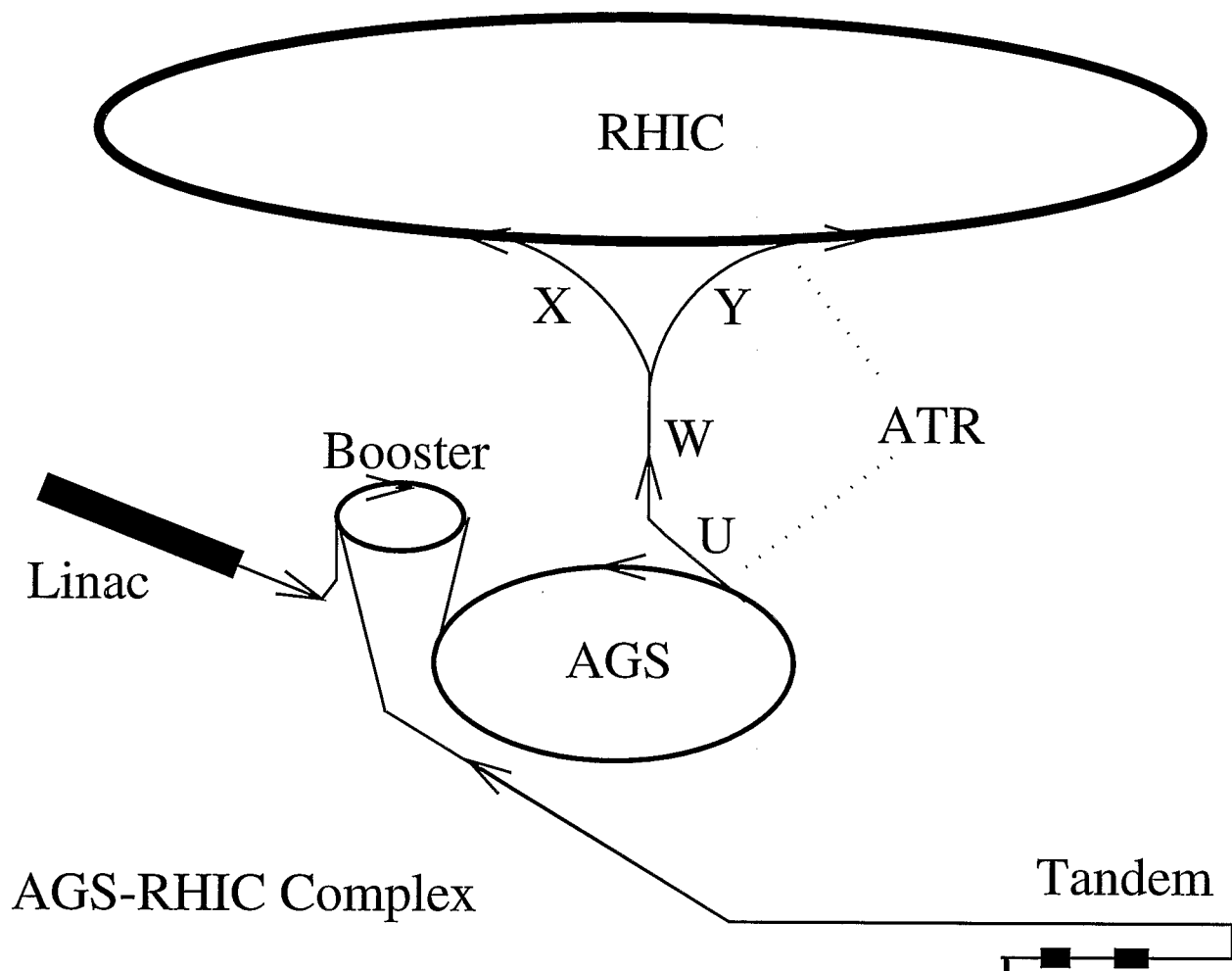
First RHIC Sextant Test — Results and Accomplishments

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RHIC Accelerator Physics

1. Introduction
2. Beam Test
 - * Beam Quality Measurements
 - * Machine Lattice Studies
 - * System Performance and Stability
3. System Test
4. Conclusions

Schematic layout of the RHIC complex.



- Full sextant test: (Au) beam and system
- Dec. 96 — Feb. 97

1. Introduction

Sextant Test milestones:

- Preparation & AGS Study (Dec. 9 — 22, 1996):
 - AGS extraction condition & beam parameter optimization
 - software debugging
 - system test
- ATR Study (Jan. 10 — 21, 1997):
 - Jan. 10: beam injected into ATR
 - Jan. 11: beam hit ATR beam dump in < 8 hours
- Sextant Beam Test (Jan. 22 — Feb. 2, 1997):
 - Jan. 20: cool down starts
 - Jan. 24: Sextant commission granted
 - Jan. 25: safety done, lines unlocked
 - Jan. 26, 14:09 — beam hit Sextant dump in ~ 30 hours
- System Test without beam (Feb. 3 — 28, 1997):
 - * Once passing the Lambertson, the beam traversed the Sextant and hit the dump without activating any correctors
 - * Total beam study ~ 1 week

Sextant Test scope:

- Beam to the dump: establish nominal conditions
- Beam test:

Beam Quality Measurements

Machine Lattice Studies

System Performance and Stability

- With $^{197}\text{Au}^{79+}$ beam in RHIC
- Total 81 shifts, including 17 owl shifts

RHIC Accelerator Physics Group

AGS Main Control Room crew

AGS/RHIC Controls Group ...

- System test:

- including all accelerator systems

magnets and power supplies

beam permit and quench protection

rf

vacuum

instrumentation

injection

cryogenics

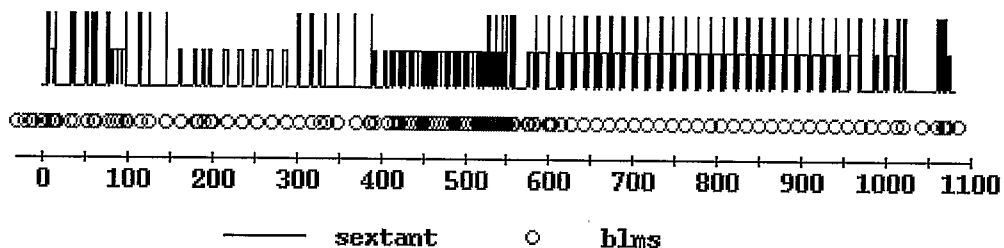
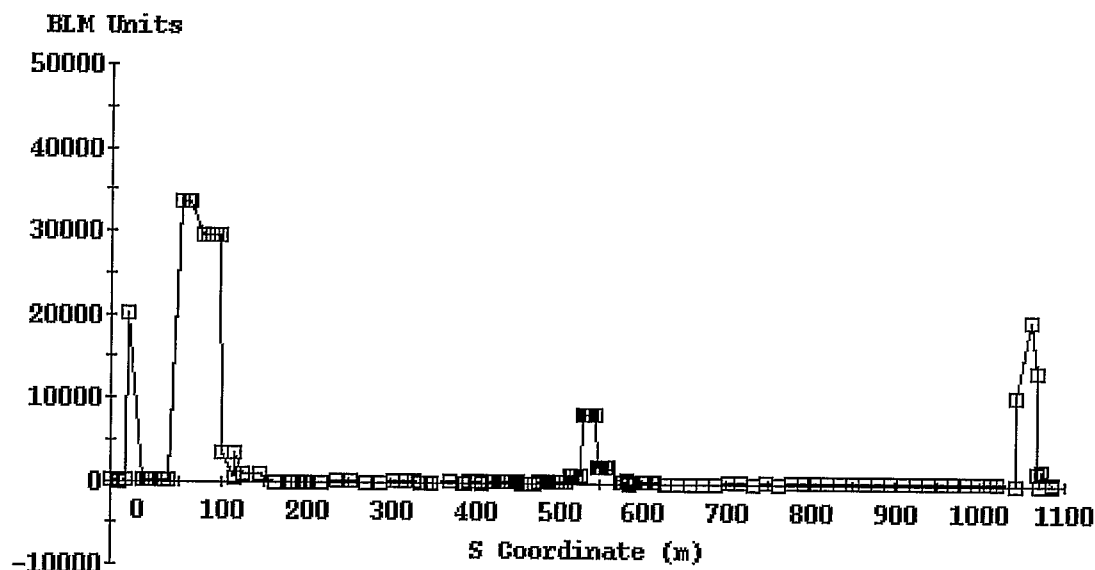
controls and database ...

- Radiation fault studies

First beam in RHIC: Loss Monitor readings

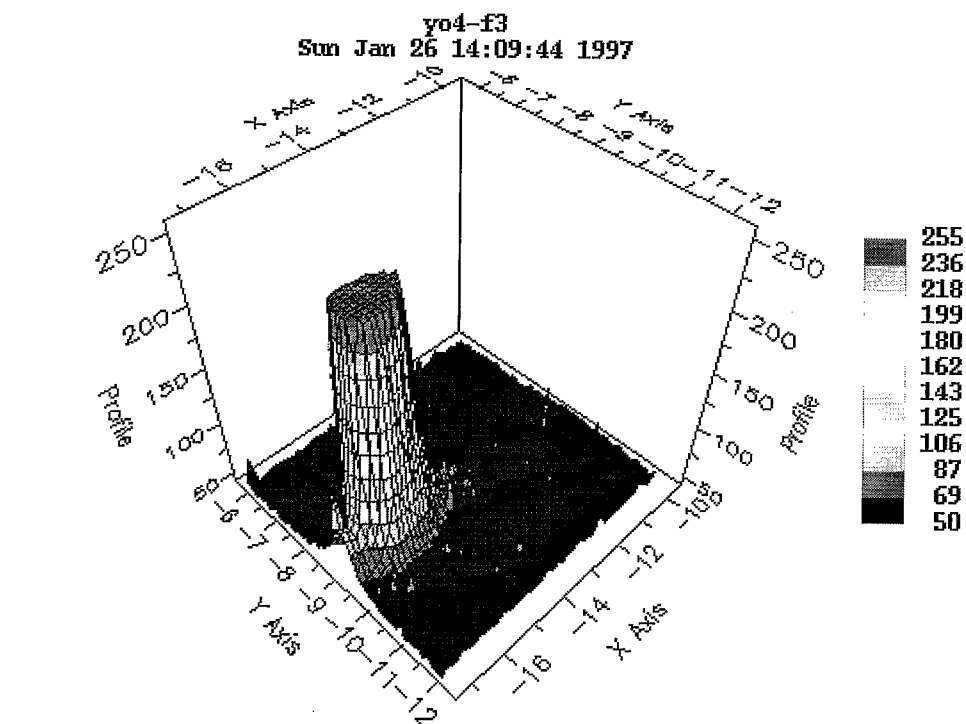
Lattice: Sextant Date/Time: Sun Jan 26 14:08:37 1997

Comment: Beam fully transported to sextant profile monitor

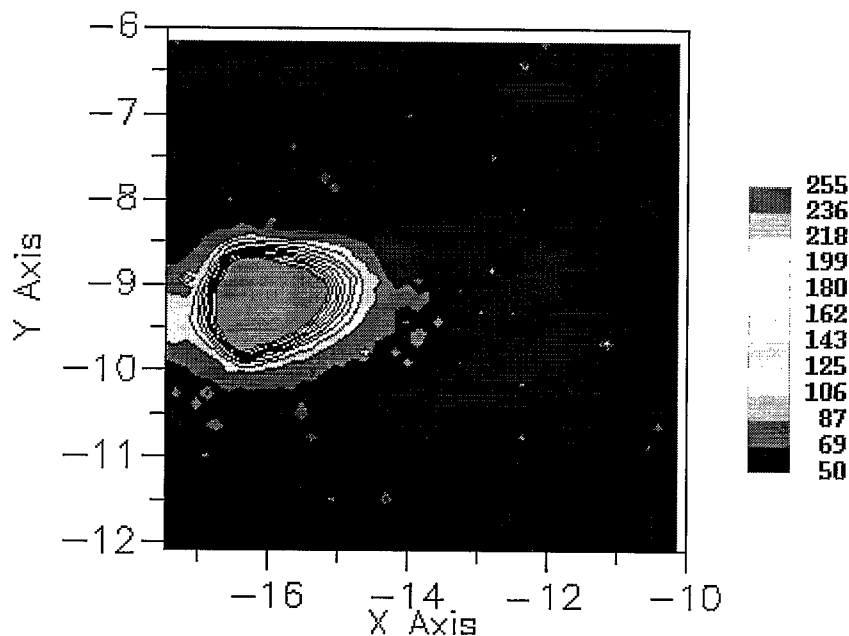


One of the first Beam Loss Monitor readings, showing loss at ATR stripping flag (uf2), sextant entrance, and sextant dump.

First beam in RHIC: Profile Monitor readings



Centroid $X = -14.1188$ $Y = -8.86515$ mm
Center $X = -16.2776$ $Y = -8.82974$ mm
Sigma Max = 1.08918 Min = 0.631376 mm with Theta = 0.0340329
Intensity = 1020872
Attenuation = 0%



2. Beam Test

2.1. Beam Quality Measurements

Goal: to achieve the nominal RHIC beam

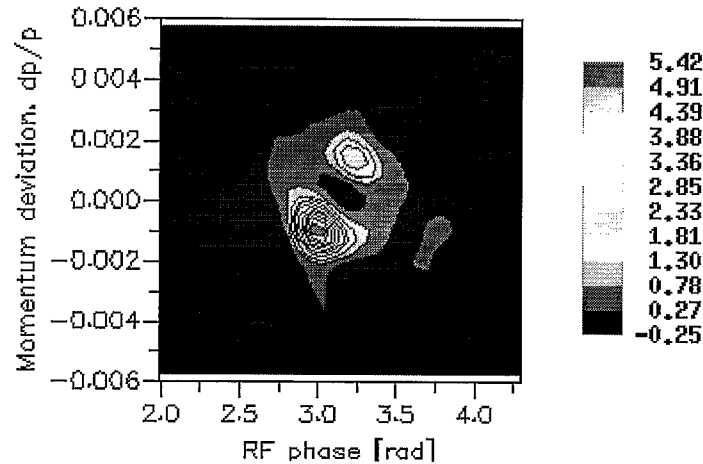
| | |
|------------------------|--|
| Longitudinal emittance | $0.2 \sim 0.5 \text{ eV}\cdot\text{s}/u$ |
| Transverse emittances | $10 \text{ mm}\cdot\text{mr}$ |
| Intensity | 10^9 ions per bunch |
| Energy (γ) | 12.6 |
| Shot-by-shot stability | |

Beam parameter measured mostly in AGS

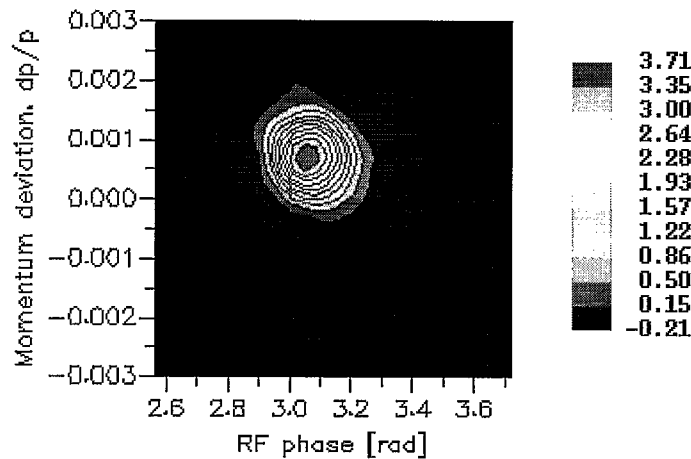
Confirmed by measurements in ATR & Sextant

Longitudinal phase-space reconstruction:

Radon Reconstruction, AGS Au+77 γ
Extraction, 0 deg γ

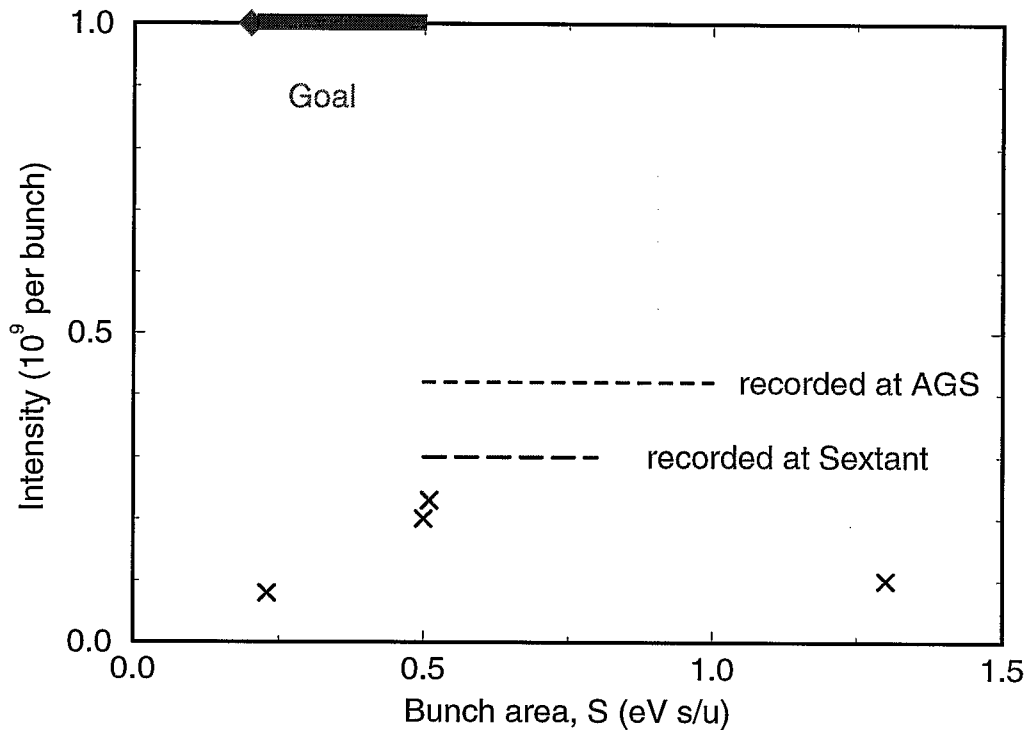


Radon Longitudinal Phase Space Reconstruction
AGS Au77+, 01/12/97



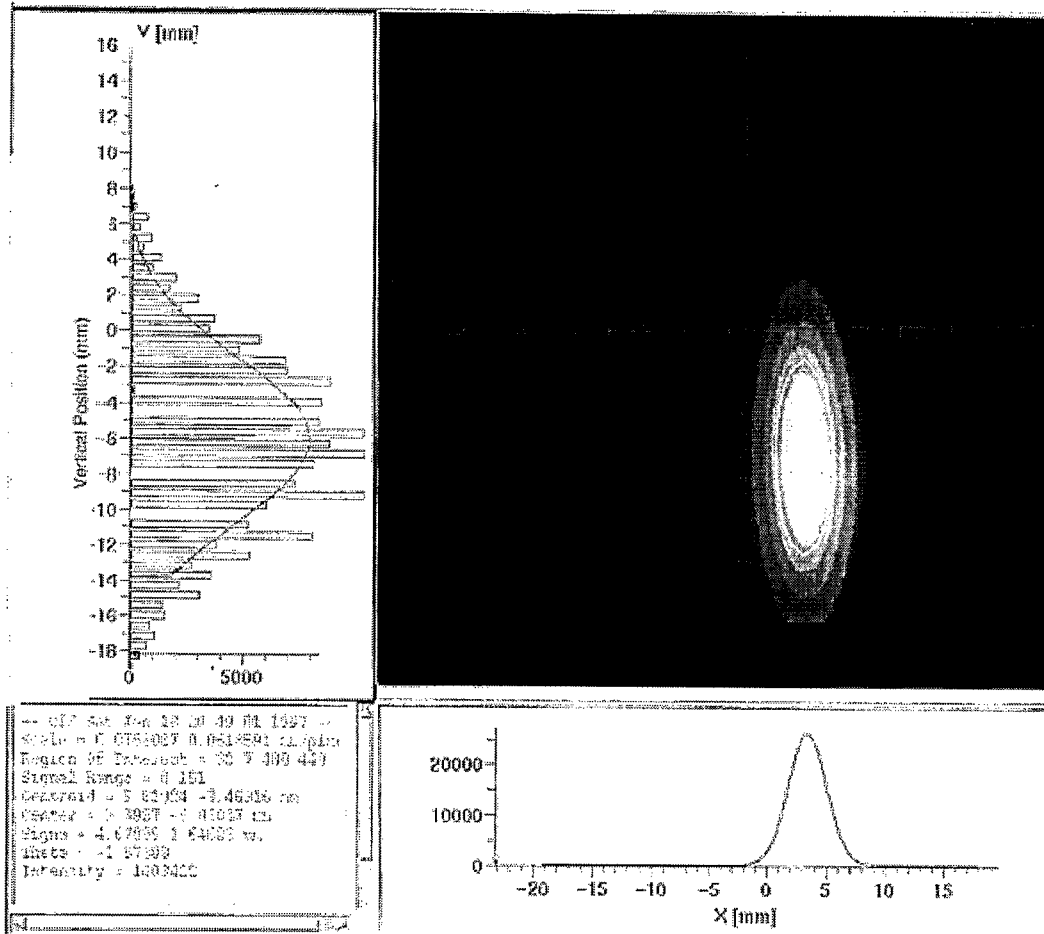
Tomographical reconstruction of the longitudinal phase space of a Au⁷⁷⁺ beam in AGS on (a) Dec. 15, 1996 ($S=1.5$ eV·s/u) and (b) Jan. 12, 1997 ($S=0.3$ eV·s/u), showing improvement of merging at bunch coalescing.

- Energy: $\gamma = 12.15 \pm 0.1$
 - B field measured in AGS using Gauss clock plus Hall probe
 - confirmed with power supply setting in ATR bends
- Intensity: typical 2×10^8 , up to 4×10^8 /bunch
 - measured consistently with Beam Current Transformers in AGS, ATR, and Sextant
- Bunch area: typical $S = 0.5 \pm 0.1$ eV s/u
 - AGS Wall Current Monitor profile
 - rf voltage calibrated with transition phase jump
 - cable bandwidth broadening subtracted (~ 2 ns measured)



Au^{79+} beam intensity and bunch area during the first Sextant Test.

- Transverse emittance: $\epsilon_{x,y} = 10 \pm 1$ mm mr
 - IPM measurement in AGS considering the momentum spread
 - Flag (Fluorescent Screen Profile Monitor) measurement in ATR & Sextant
 - Novel (electron collecting) IPM measurement in ATR
 - Automated archiving & on-line analysis



Transverse beam profile in W-line recorded on Flag wf3 and IPM.

2.2. Machine Lattice Studies

- **Momentum aperture scan**

- Vary beam radial position in AGS to scan AGS extraction
- Vary ATR and Sextant magnet power supplies to scan various bends
- Bottle neck at AGS extraction when extraction bump is excited; minimum aperture $\Delta p/p \sim 1\%$

- **Orbit correction**

- Automated orbit correction worked only for U and W line
- Manual orbit correction elsewhere (BPM not reliable)

- **Transfer matrix & difference orbit**

- Transfer matrix checked by the difference orbit method: comparison of orbit difference for an up stream kick
- On-line lattice modelling in BPM application for comparison

- **Dispersions in ATR and Sextant**

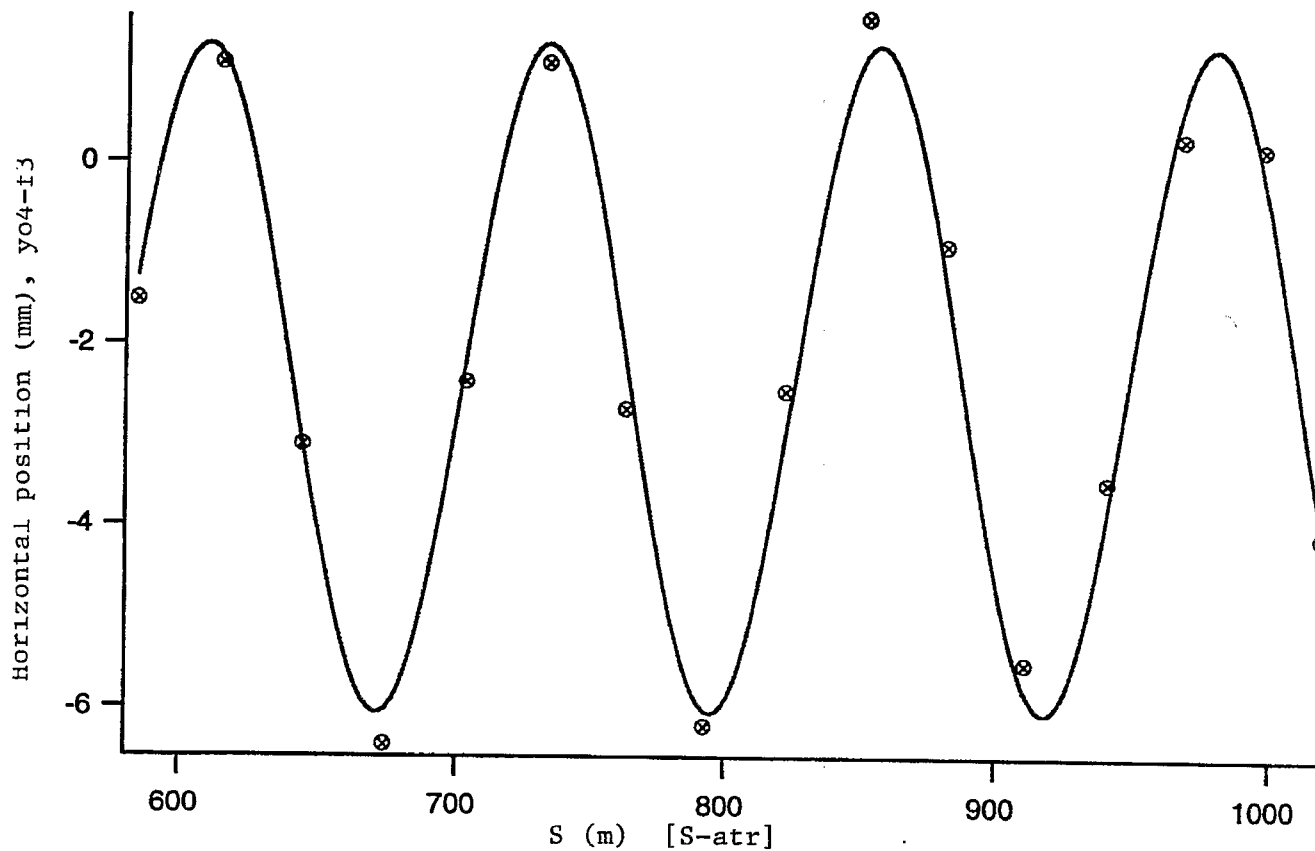
- Measured beam centroid position with Flags and BPMs while varying AGS radial position and recording frequency
- AGS extraction condition changes, mismatched with ATR

- **Optics (β , phase advance, chromaticity)**

- Phase advance measurement crucially done with the single flag in Sextant
- Phase advance as functions of radial position and quad strength

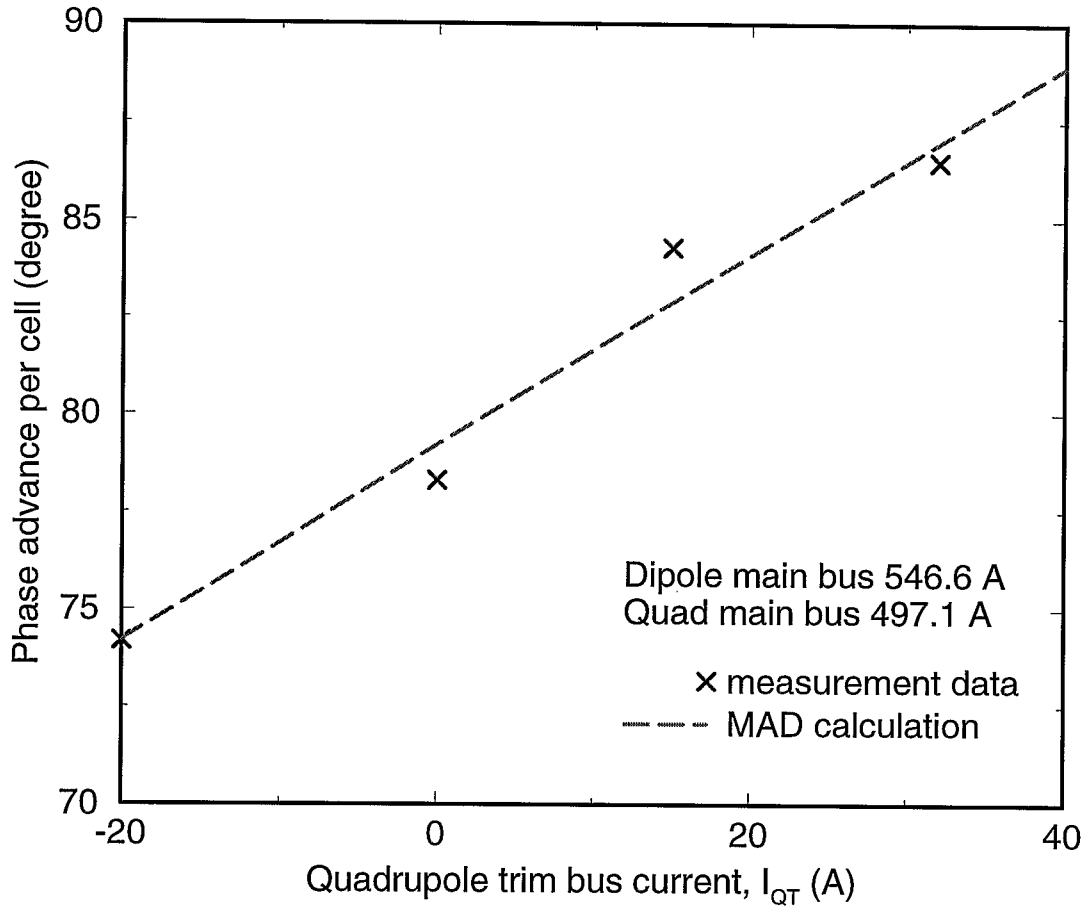
Poor men's way of phase advance measurement:

- BPM in Sextant not reliable
- Sequentially vary each horizontal & vertical dipole corrector strength
- Record beam centroid position on the only flag near Sextant dump,



Sextant phase advance measurement using corrector kicks and Flag position observation: beam centroid position vs. dipole corrector location excited at 1 A at injection.

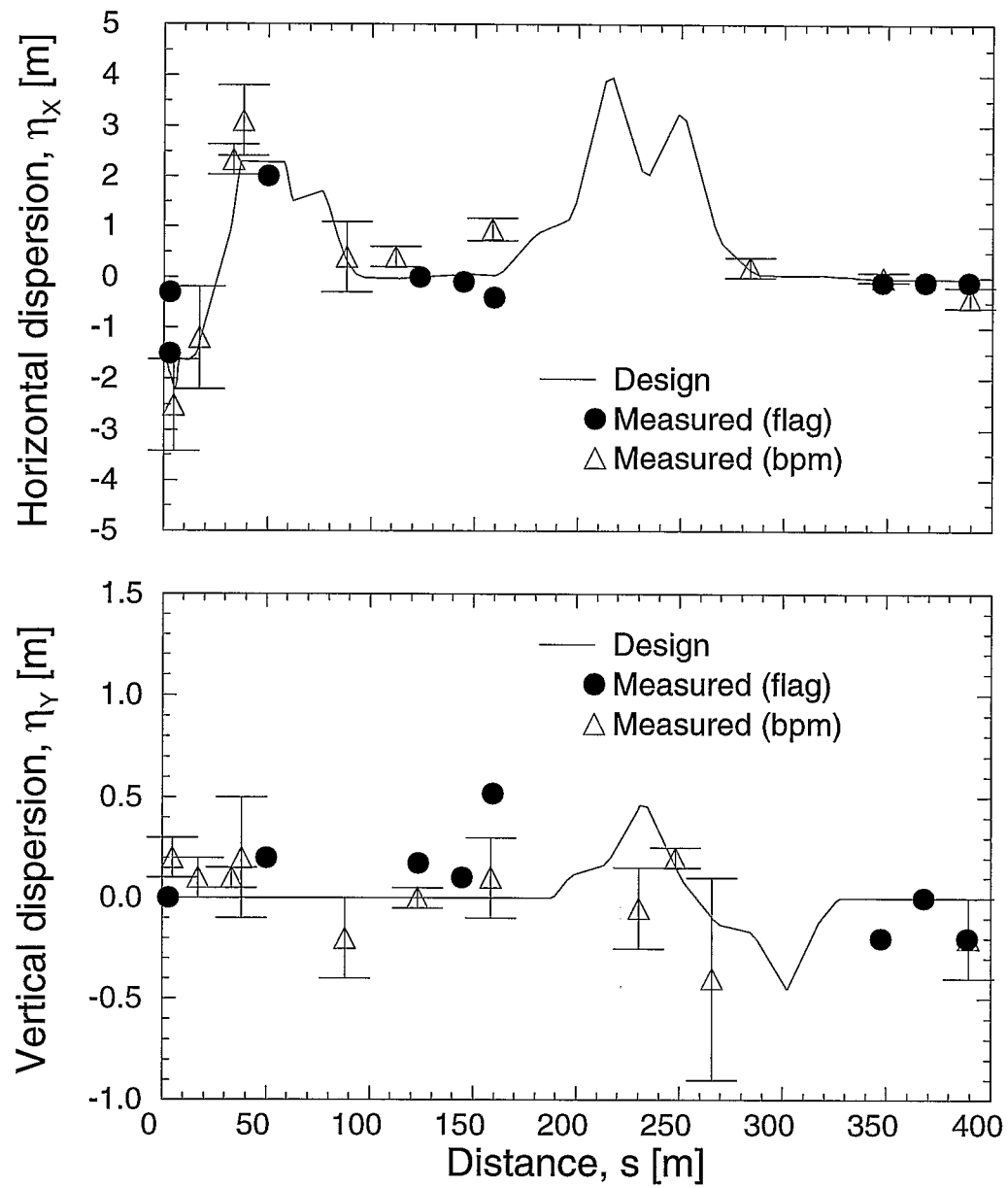
Phase advance vs. quad strength:



Comparison of beam measurement and MAD modelling (pre-installation bench measurement) on horizontal phase advance per cell as a function of arc focusing quad strength.

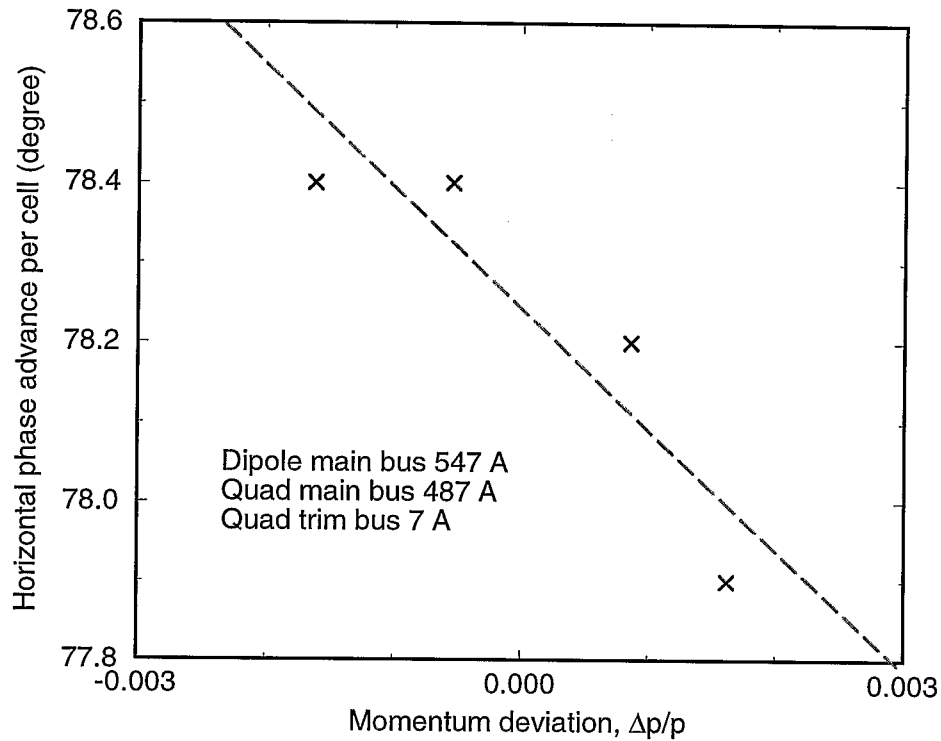
- Sextant power supply: 1 main dipole (~ 550 A), 1 main quad (QF and QD, ~ 500 A), 1 trim quad (QF only, ± 30 A)
- MAD modelling using magnet Integral Transfer Function cold measured at 660 A; dead reckoned calculation
- Agreement within 0.6%

Dispersion measurement:



Dispersion in ATR measured by varying beam momentum in AGS.

Chromaticity measurement:



- measure phase advance for different radial orbits
- possible systematic error in AGS momentum calibration

Comparison on sextant natural chromaticity between measurement and MAD modelling: relative phase advance per unit momentum deviation.

| | |
|---------------------|-------------|
| ξ (measurement) | ξ (MAD) |
|---------------------|-------------|

-7

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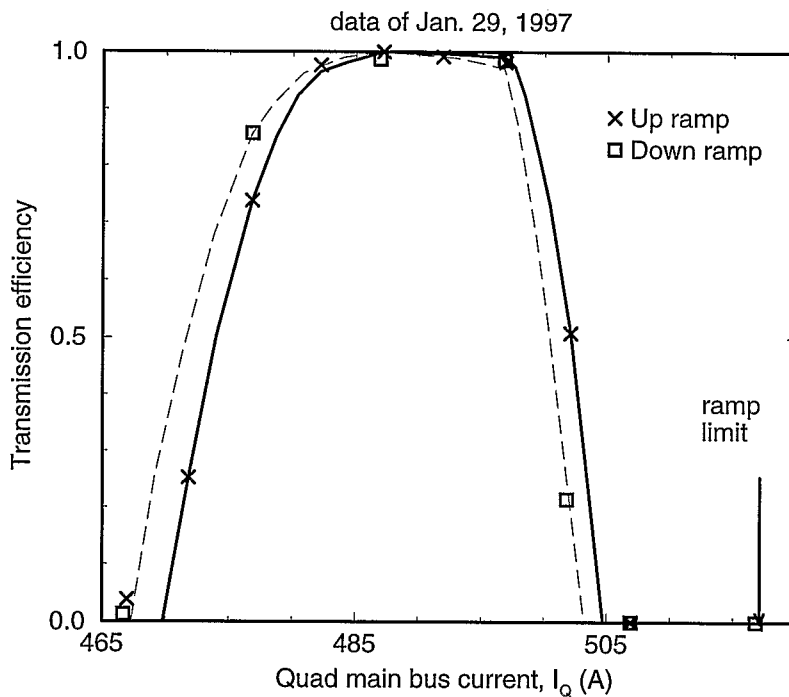
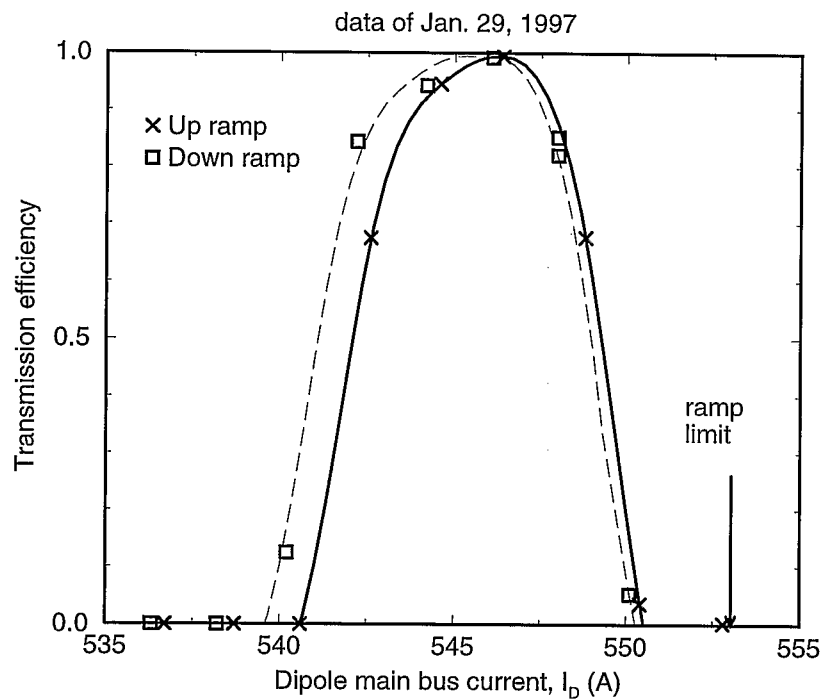
2.3. System Performance and Stability

— Beam based accelerator system study:

- Beam instrumentation evaluation
- Injection position repeatability
- Kicker performance and kicker noise
- Multi-bunch stability
- Magnet hysteresis

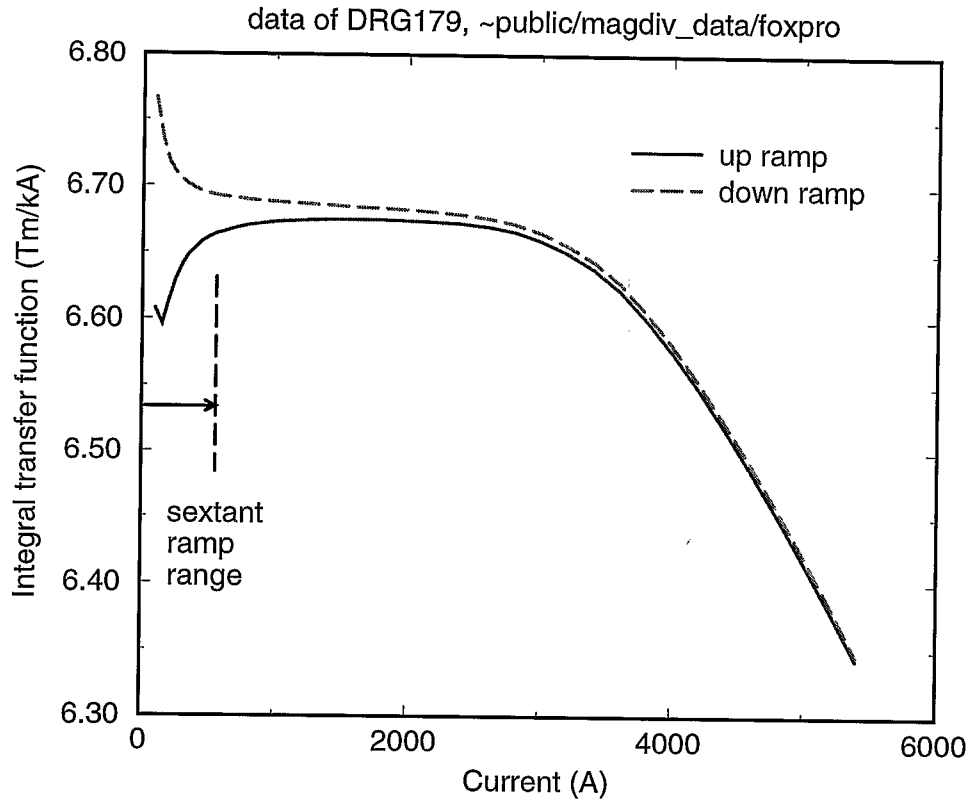
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Magnet hysteresis:



Sextant dipole and quad hysteresis measurement by transmission efficiency scan.

Bench measurement:



Integral Transfer Function of an arc dipole at 660 A.

- Beam scan is limited by maximum allowable current (~ 600 A)
- In bench measurement, current is ramped to 5500 A

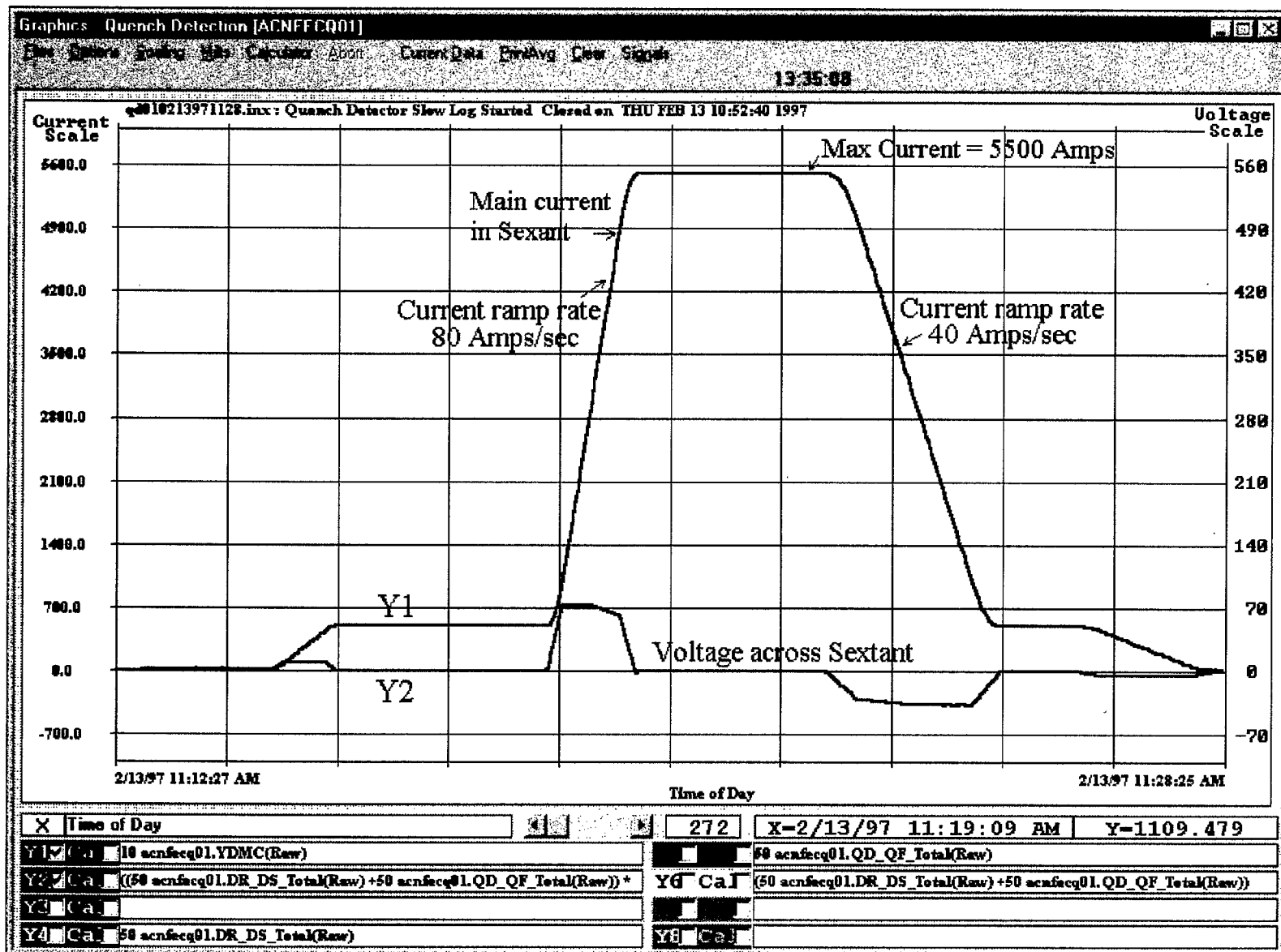
Comparison on sextant arc dipole hysteresis between beam measurement and bench (Integral Transfer Function) measurement.

| Magnet | Δ_h (beam) | Δ_h (ITF) |
|--------|-------------------|------------------|
| Dipole | ≥ 1.1 A | 1.8 A |
| Quad | ≥ 2.3 A | 2.3 A |

3. System Test

3.1. Magnets and power supplies

- Except for DX, all types of magnets are involved
- Magnets repeatedly ramped to 5,500 Amps, and kept at full current for 12 hours
(nominal operating current 5 kA for 10 hours)
- Magnet ramping rate 10% higher than the nominal
- No quench for all magnets (previously 20% cold tested)
(except for intentional quench induced by heaters)
- Bench measurement of magnet Integral Transfer Function confirmed by beam measurement with 0.6% accuracy



Current and voltage waveforms during a RHIC sextant test current cycle.

3.2. Instrumentation

- Beam Loss Monitors (BLM)
commissioned in single pass & ring operation mode
60 channel for ATR + 60 channel for Sextant
- Beam Position Monitors (BPM)
total 24 planes
ATR U and V line BPM satisfactory;
worked for 4-bunch trains
low level problems in Sextant BPM; not stable
software communication bugs fixed after the Test
- Beam Current Monitors (BCM)
4 in ATR, 1 in Sextant; all reliable
worked for 4-bunch trains
- Beam Profile Monitors (Flags)
8 in ATR, 1 in Sextant; all reliable
worked for 4-bunch trains
- Ionization Profile Monitors (IPM)
commissioned in ATR; excellent agreement with Flags

3.3. Cryogenics

- cool-down in 48 hours; stable through the Test
- warm-up in 24 hours with warm-up heaters

3.4. Vacuum

- helium leaks were observed in insulating vacuum volumes
- large leaks located and repaired; small leaks handled with turbopump stations

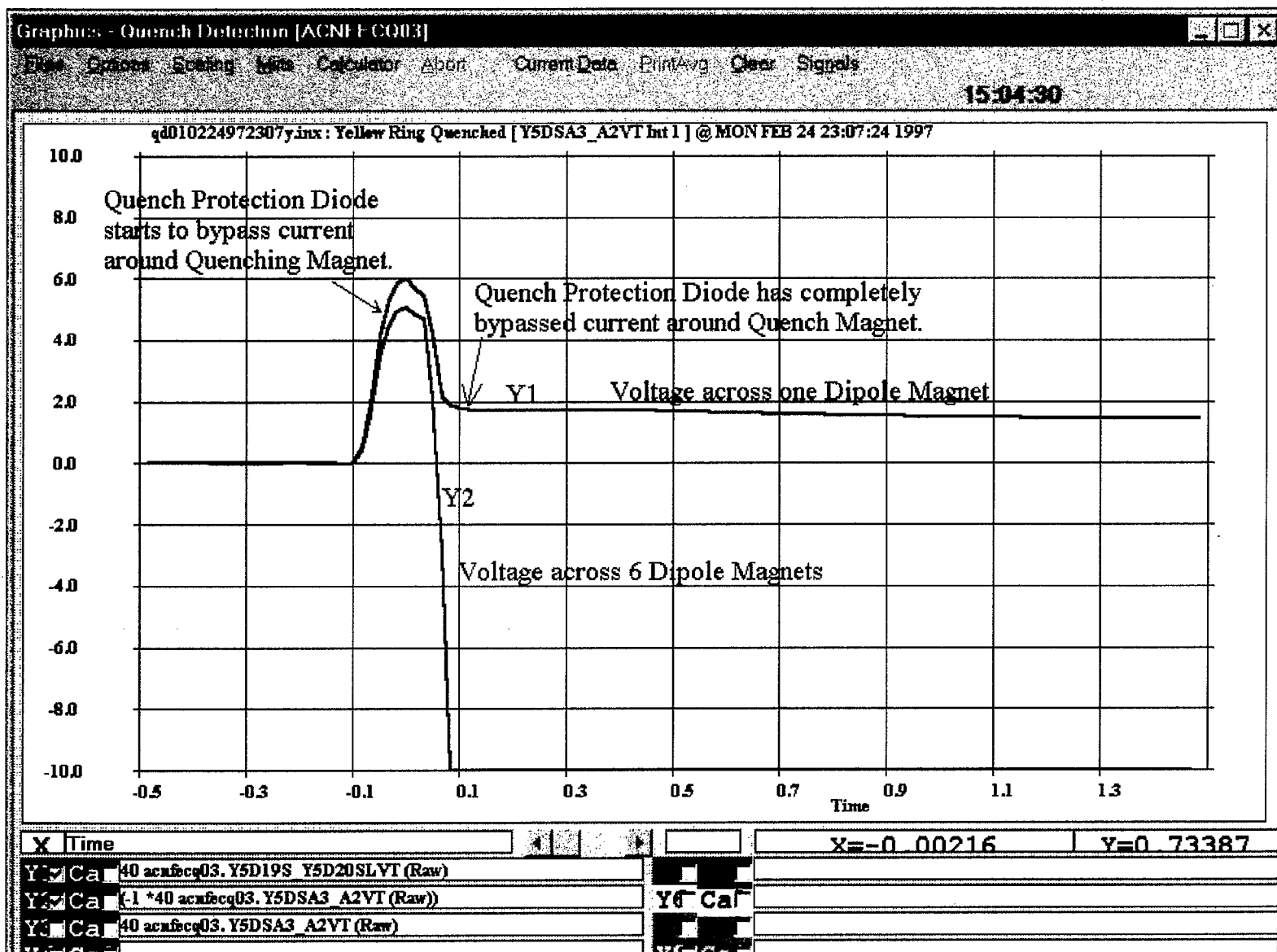
actual pressure inside cold bore $< 10^{-11}$ Torr

warm bore beam vacuums maintained at 10^{-9} Torr with ion sputter pumps

insulating vacuum ranged from 10^{-7} to 10^{-3} Torr (at the leak); adequate

3.5. Beam permit and quench protection

- functioned properly in the Test
- disabled beam injection in the case of closed vacuum valves
- quench protection tested during the warm-up



Dipole Magnet Quench at 5500 Amps
Induced by Warm-up heater.

3.6. RF

- A 197 MHz storage cavity was successfully run at 1.1 MV
(nominal 1 MV)
- fully demonstrated the driver amplifier, power amplifier, cavity chain, and beam-system synchronization

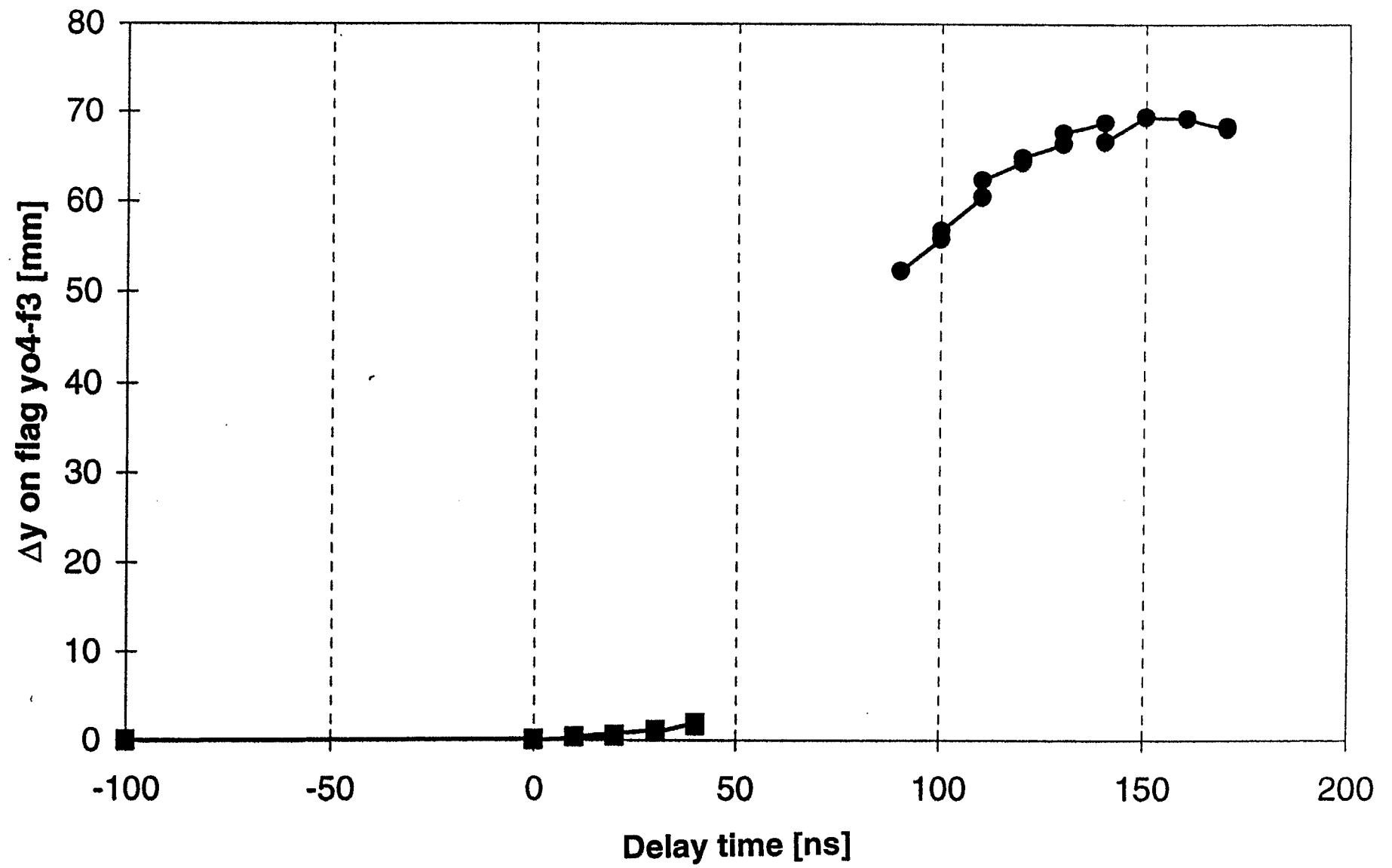
3.7. Injection

- all requirements on the injection kicker are met:
timing, strength, rise time
- shot-to-shot stability tested for multi-bunch injection
- initially using a dipole corrector; later using a kicker

3.8. Controls and database

- design validated during the beam test, integrating all other systems

A,B,C,D



4. Conclusions

- A major milestone - the First Sextant Test - was passed successfully commissioning all major accelerator systems.
- Beam emittances reached the design value; beam intensity reached 40% of the nominal value.
- Machine lattice was verified; agreement between beam and bench measurement on phase advance within 0.6% accuracy.
- Sextant Test was an excellent practice for the full commissioning in 1999.